Large-Area, Dual-Chamber Magnetron-Sputtering Unit for Preparation of CIGS Thin Film Solar Cells

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ABSTRACT

$CuIn_{1-x}Ga_xS_2$ (CIGS2) thin film solar cell samples are being prepared routinely on sodalime glass substrates and on metallic foils. PV parameters of a CIGS2 solar cell on SS flexible foil measured under AM 1.5 conditions at NREL were: V_{oc} = 788 mV, J_{sc} = 19.78 mA/cm^2, FF = 59.44%, η = 9.26%. For this cell, AM 0 PV parameters measured at the NASA GRC were: V_{oc} = 802.9 mV, J_{sc} = 25.07 mA/cm^2, FF = 60.06%, and η = 8.84%. A large-area, dual-chamber magnetron-sputtering unit has been fabricated. Three 4” x 12” DC magnetron sputtering sources have been installed in the larger chamber for Mo, CuGa, and In sputter deposition. Two 4” x 12” RF magnetron sputtering sources have been installed in the smaller chamber for ZnO and ZnO:Al bilayer window deposition. Selenization and sulfurization of 4” x 4” samples is planned using a furnace being donated by the Siemens Solar ind.

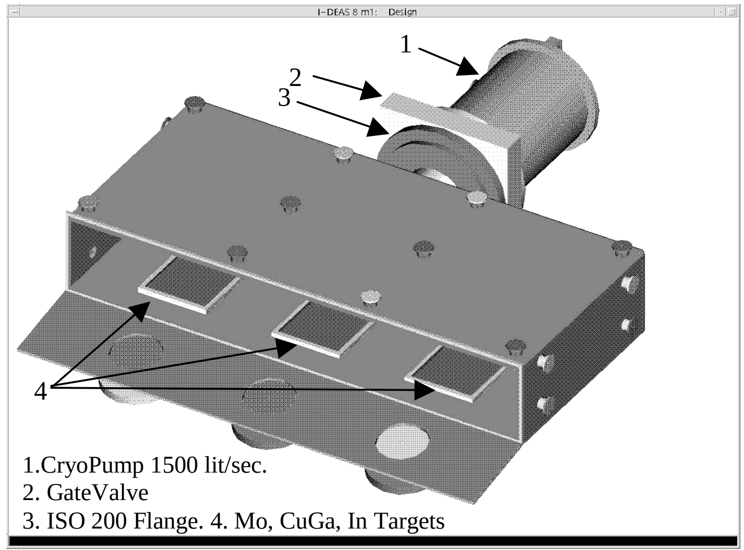

Fig. 1: Large chamber with three sputtering targets, Gate valve and Cryo Pump (1500 lit/sec).

1. Introduction

$CuIn_{1-x}Ga_xS_2$ (CIGS2) thin-film solar cells are of interest for photovoltaic conversion because of the near optimum bandgap of 1.5 eV [1]. CIGS2 thin films prepared with gallium content x of 0.31 and 0.36 have been found to have a bandgap of 1.71 eV and 1.76 eV respectively [2]. Recently, large-grain CIGS2 films with Ga content x in the range 0.4 to 0.5 have been prepared [3]. Such films will be suitable for fabrication of the front cell in a tandem structure. FSEC PV Materials Laboratory has facilities for magnetron sputter deposition of molybdenum back contact layer and CuGa/In metallic precursor layers, selenization and sulfurization of metallic precursors, CdS chemical bath deposition and ZnO/ZnO:Al RF sputter deposition. Earlier, the substrate size was limited to 1” x 1”. A large-area, dual-chamber magnetron-sputtering unit has been fabricated recently. The chambers are equipped with cryopumps, two-stage mechanical vacuum pumps, throttled-gate valves, mass-flow controllers for argon and oxygen, and convectron and Bayard-Alpert ionization gauges. A large number of feed-thru ports have been provided to both the chambers for rotation and electrical feed-thru’s. This will permit addition of *in situ* diagnostic tools.

The large chamber (Fig. 1) has three 4” x 12” DC magnetron sputtering sources, installed for sputter deposition from molybdenum, indium, and copper, CuGa (22%) or CuGa (67%) targets. A linear substrate movement set-up has been fabricated for “in line” deposition of molybdenum back contact and Cu-Ga/In metallic precursors. Presently the movement of the substrates is done manually. Precise movement using stepper motor will be done in the near future.

The small chamber (Fig. 2) has two 4” x 12” RF magnetron sputtering sources, installed for RF sputter deposition from ZnO and ZnO:Al targets.

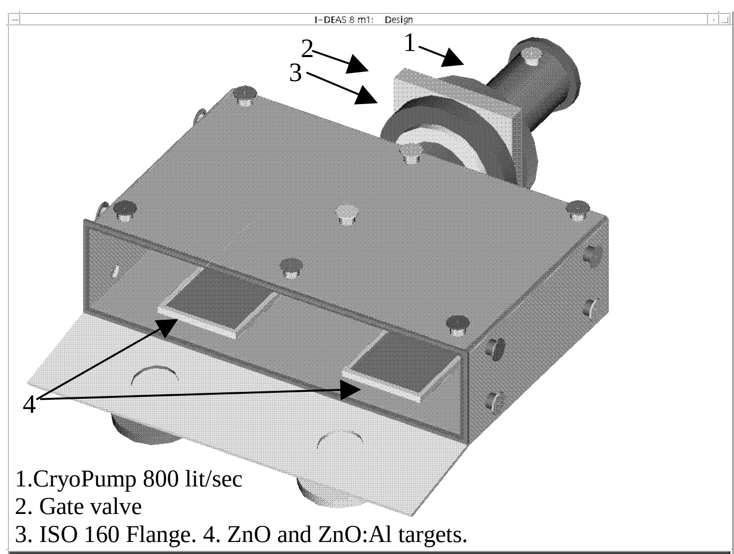

Fig. 2: Small Chamber with ZnO and ZnO:Al targets, Gate Valve and Cryo Pump (800 lit/sec)

The thickness uniformity along the 12” dimension is expected to be better than ± 2% over the center width of 5” and better than ± 3% over the center width of 6” for linear substrates motion along the 4” dimension. Moreover, the sputtering sources are expected to provide excellent (>40%) target utilization. A four-hearth e-beam source has also been procured for vacuum evaporation of Ni/Al contact grids. The vacuum chambers were designed at FSEC and were built elsewhere based on FSEC design. The complete system was designed and constructed at FSEC. Several Graduate students have been trained in the design and construction of the dual-chamber magnetron-sputtering unit. This experience will be valuable to them and to the PV community.

2. Experimental Technique

The routine experimental technique in fabricating CIGS2 thin film solar cells at FSEC consists of two stages. First stage is the sputter deposition of Cu+Ga and In on Mo coated glass substrates or SS foils. This stacked elemental layer is sulfurized in H_2S: Ar gas environment using a three-zone furnace. The Cu-rich stoichiometry during the growth of CIGS2 films results in an improved morphology, i.e. enhanced grain sizes of the polycrystalline films. Presently we have the limitation in sulfurization process for only 1” x 1” cells. Recently, Siemens Solar Industries (SSI) has agreed to donate a selenization and sulfurization unit, in which large 4” x 4” samples can be selenized and sulfurized. The copper rich Cu_xS phase, precipitating at the top during sulfurization is etched using 10% KCN. This is followed by deposition of CdS buffer layer by chemical bath deposition (CBD) and ZnO window layer. Presently the chemical bath deposition is limited to 1” x 1” samples but we have plans for the fabrication of new CBD CdS facility both for large area (4” x 4”) solar cells. Also presently the deposition of ZnO and ZnO:Al is also limited to one 1” x 1” sample per run. However, with fabrication of the large-Area, inline chamber (Fig. 2), we will be able to sputter deposit more samples in a single run.

3. Round Robin AES and SIMS Analysis

Together with NREL and University of Illinois, FSEC has carried out the round robin, Auger electron spectroscopy (AES) and secondary ion mass spectroscopy (SIMS) analysis of CIGS and CIGS/CdS samples prepared at the SSI, NREL, and Institute of Energy Conversion. The results show that SIMS analysis using both oxygen and cesium beams can provide important and useful information. The results are being presented at the National CIS Thin Film Partnership Program Meeting.

4. IxV characteristics of CdTe modules

Measurements of IxV characteristics of seven CdTe modules from First Solar (formerly Solar Cells Inc) have been carried out periodically. The results have been submitted to NREL and First Solar.

5. Results and Discussion

X-ray diffraction (XRD) pattern of the as-deposited (Cu+Ga)/In metallic precursors indicated the presence of

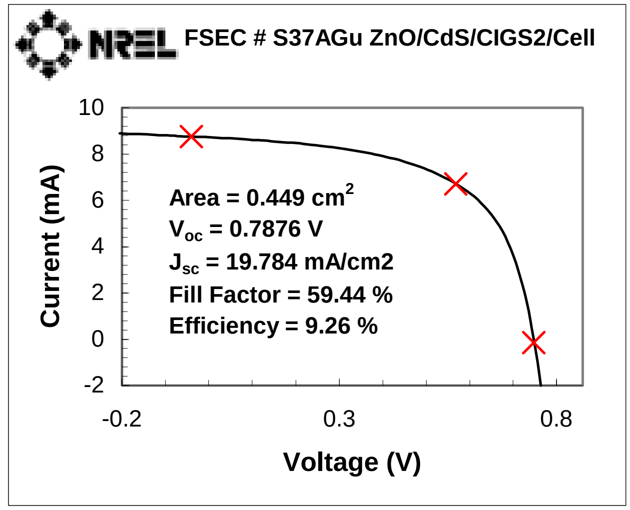

Fig. 3. I - V curve of CIGS2 thin film solar cell on SS foil.

highly oriented $Cu_{11}In_9$ phase without any elemental or alloy phases. XRD pattern of near stoichiometric, slightly Cu-poor, etched CIGS2 thin film showed a (112) texture growth of chalcopyrite $CuIn_{0.7}Ga_{0.3}S_2$ phase with a = 5.67 Å and c = 11.34 Å [4]. PV parameters of a CIGS2 solar cell on 127μm thick SS flexible foil measured at NREL under AM 1.5 conditions were: V_{oc} = 788 mV, J_{sc} = 19.78 mA/cm^2, FF = 59.44%, □ = 9.26% (Fig. 3). For this cell, AM 0 PV parameters measured at the NASA GRC were: V_{oc} = 802.9 mV, J_{sc} = 25.07 mA/cm^2, FF =60.06%, and efficiency □ = 8.84% [4].

6. Acknowledgements

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